Optics for Compact, High-Performance Imaging Spectrometers

An off-axis, telecentric telescope/camera is combined with convex diffraction grating spectrometers.

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Several high-fidelity imaging spectrometers have been designed with convex diffraction gratings for wavelengths ranging from the ultraviolet to the thermal infrared. All the designs are telecentric and can be combined with a flat-field, three-mirror anastigmatic telescope that also functions as a panchromatic camera.

The spectrometers are derivatives of an elegant relay disclosed by Offner in the early 1970's. The original "Offner relay" was a mask aligner consisting of two concentric spherical mirrors for projecting a telecentric image of a mask onto a semiconductor wafer. A few years later Thevenon suggested replacing the convex secondary mirror of the relay with a diffraction grating to form an imaging spectrometer.

In 1992, an Italian firm decided to act on Thevenon's suggestion and developed the first compact Offner imaging spectrometer for the Cassini mission to Saturn. Dubbed the "VIMS-V", the prototype was delivered to the Jet Propulsion Laboratory (JPL) for integration into the "Visible Infrared Mapping Spectrometer." The grating for the VIMS-V was manufactured by a German company using holographic recording and ion-beam milling. The gratings can also be fabricated using electron-beam lithography.

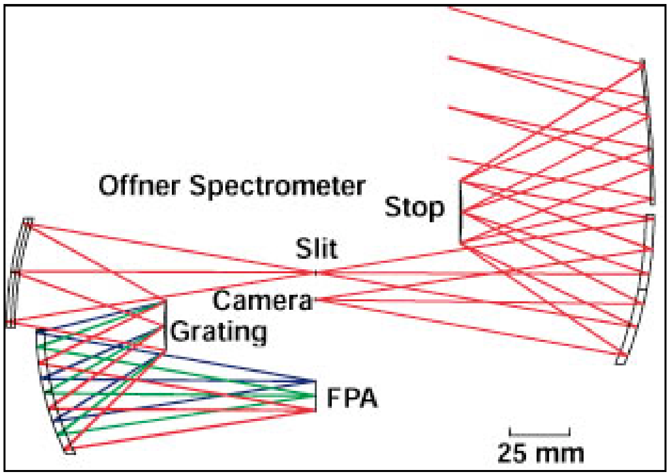
The Offner spectrometer was initially developed to overcome the inherent limitations of another popular concentric spectrometer invented by Dyson in the late 1950's. The Dyson uses a concave grating and controls optical aberrations with a thick plano-convex lens placed immediately in front of the slit-detector plane. Unfortunately a lens in this position back-scatters the input white light directly onto the focal plane array (FPA), and it does not leave space for a cold stop. Without a cold stop the entire spectrometer must be cooled to the FPA temperature, thereby increasing the low temperature cooling load by a factor of 10 or more.

A cold Dyson spectrometer would also be sensitive to misalignment because its grating reflects the chief rays at large angles to the optical axis before they can be made telecentric by the lens. Hence, a small shift in the position of the lens distorts the image and the spectrum. For example, a shift within a typical position tolerance of 10 μm generates 8 percent distortion at the edge of a spectrum only 5 mm long.

An acceptable uncalibrated distortion limit is 1 percent of a pixel, which is easily controlled in the Offner when the spectrum is confined to a narrow, annular zone less than a few millimeters wide. Two examples of miniature Offner designs with less than 10 nm distortion (0.1 percent of a pixel along a 16 mm image) are listed at *http://focus.software.com/file-exchange/index.html*.

Distortion increases as the cube of the spectral length, so it becomes increasingly difficult to maintain performance across large-area FPAs. The new designs use several variations of Offner configurations to maintain high performance across large areas. In the design shown in the figure, the image is 16 mm long and the spectrum is 12 mm long, yet the spectral distortion is less than 1 percent of a pixel. This is accomplished by tilting the two relay mirrors of a lateral Offner configuration (the grating and FPA are displaced laterally from the slit line).

In another design the image is 12 mm long and the spectrum is 16 mm long, so the Offner is put into a vertical configuration (the grating and FPA are displaced vertically above the slit line). A single, aspheric relay mirror helps control optical aberrations. The vertical configuration enables the grating to be divided into two sections that are blazed for positive and negative diffraction orders. Each section is optimized for its own FPA spectral passband and resolution. This technique is used in an imaging spectrometer being developed for the comet rendezvous mission *Rosetta*. The spectrometer can cover the 0.25 – 5 μm spectral band without the need for a dichroic beam splitter. Dichroic beam splitters limit the spectral passband considerably, especially when the passband extends from the ultraviolet to the infrared.



This **Imaging Spectrometer/Camera** uses a convex grating in a lateral Offner configuration to reduce distortion to less than 1 percent across a 12-mm spectrum with a 16-mm image.

This work was done by Francis Reininger of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* **free on-line at www.nasatech.com** *under the* ***Physical Sciences category.***

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